

Assume $P(n)$ is divisible by 3 for any $n = k$ where $k \in \mathbb{Z}$: (inductive step begins)

$$\text{Let } P(k) = k^3 + 2k = 3a:$$

$$\begin{aligned} P(k+1) &= (k+1)^3 + 2(k+1) \\ &= k^3 + 3k^2 + 5k + 3 \\ &= (k^3 + 2k) + 3k^2 + 3k + 3 \\ &= 3a + 3k^2 + 3k + 3 \\ &= 3(a + k^2 + k + 1) \end{aligned}$$

$\therefore P(n)$ is divisible by 3 when $n = k + 1$ (inductive step proven)

As $P(n)$ is divisible by 3 when $n = 0$, and for every integer larger, then $n^2 + 2n$ is divisible by 3 for $n \geq 0$.

Sequences and series proofs

The n^{th} term or the n^{th} partial sum of a sequence or series can be found using proof by induction, though these are often difficult. You will learn more about sequences and series in Area of Study 2.

Example 1.9

Given the series $1^3 + 2^3 + 3^3 + \dots + n^3$, prove the sum of the first n terms is given by $\frac{1}{4}n^2(n+1)^2$.

$$\text{Let } P(n) = 1^3 + 2^3 + 3^3 + \dots + n^3:$$

Base case: $n = 1$

$$P(1) = 1^3 = 1$$

$$\frac{1}{4}n^2(n+1)^2 = \frac{1}{4} \times 1^2 \times (1+1)^2 = 1$$

$\therefore 1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{1}{4}n^2(n+1)^2$ when $n = 1$ (base case proven)

Assume $P(k) = 1^3 + 2^3 + 3^3 + \dots + k^3 = \frac{1}{4}k^2(k+1)^2$ (inductive step begins)

$$\begin{aligned} \therefore 1^3 + 2^3 + 3^3 + \dots + k^3 + (k+1)^3 &= \frac{1}{4}k^2(k+1)^2 + (k+1)^3 \\ &= (k+1)^2 \left(\frac{1}{4}k^2 + (k+1) \right) \\ &= (k+1)^2 \left(\frac{1}{4}(k^2 + 4k + 4) \right) \\ &= (k+1)^2 \left(\frac{1}{4}(k+2)^2 \right) \\ &= \frac{1}{4}(k+1)^2((k+1)+1) \\ \therefore P(k+1) &= \frac{1}{4}k^2(k+1)^2 + (k+1)^3 = \frac{1}{4}(k+1)^2((k+1)+1) \end{aligned}$$

As $1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{1}{4}n^2(n+1)^2$ when $n = 1$, and for every integer larger, $1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{1}{4}n^2(n+1)^2$.

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